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NEW APPROACHES OF FIBER OPTIC SENSOR AND TECHNIQUES

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1.1 Introduction

In the year 1960, laser light was invented and after the invention of laser, analysts showed interest in concentrating on uses of optical fiber correspondence frameworks for detecting, information correspondence and numerous different applications. The fiber optic correspondence framework has since turned into a definitive decision for gigabits and past gigabit transmission of information. Such fiber optic correspondence is utilized for significant distance correspondence or for sending information, voice, telemetry, and video over a PC organization or LAN. This procedure utilizes a light wave to send information over a fiber by changing over electronic signs into light. Some remarkable components of this innovation incorporate light weight, low weakening, little breadth, significant distance signal transmission, transmission assurance and such.

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Figure 1.1: Fiber Optic Sensors [1]

Fundamentally, media transmission innovation has supplanted the new advances in fiber optic innovation. The last transformation showed up as fashioners joining the useful aftereffects of optoelectronic gadgets with fiber-optic-media communications gadgets to make fiber optic sensors. A huge number related with these gadgets are regularly produced for fiber-optic-sensor applications. The limit of fiber optic sensors has expanded instead of customary sensors.

1.1.1 Fiber Optic Sensors

Fiber optic sensors are additionally considered optical fiber sensors that utilization optical fiber or detecting component. These sensors are utilized to detect certain amounts like temperature, pressure, vibration, dislodging, revolution or convergences of compound species. There are many employments of fiber in the field of remote detecting since they don't need electric force at a far off area and are little in size.

Fiber optic sensors are preeminent for unfeeling conditions, including commotion, high vibration, outrageous warmth, wet and unsound conditions. These sensors can

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without much of a stretch fit in little regions and can be situated effectively any place adaptable strands are required. The frequency shift can be determined utilizing a solitary instrument, optical recurrence area reflabrometry. The time deferral of fiber optic sensors can be fixed utilizing an instrument, for example, optical time-area reflectometer.

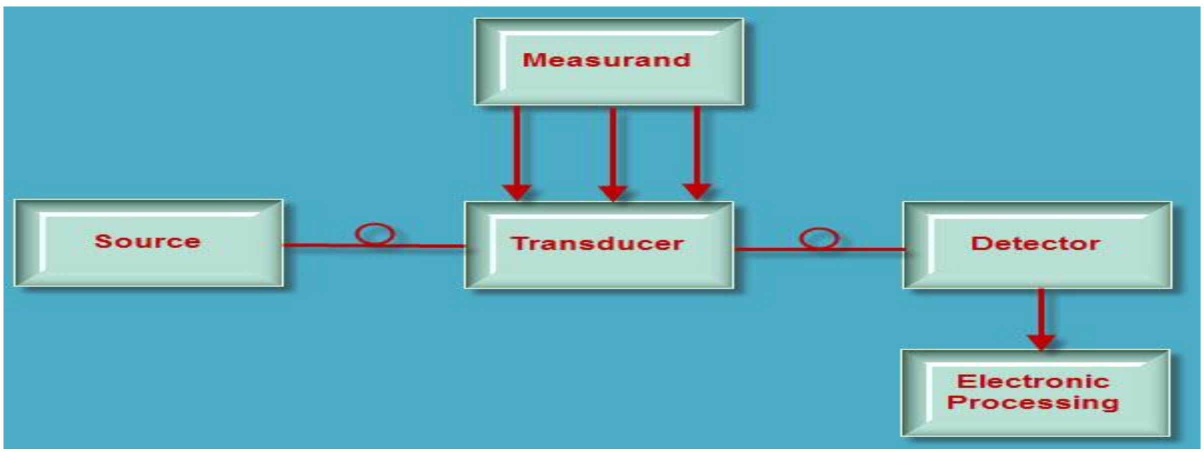

Figure 1.2: Block Diagram of Fiber Optic Sensor[1]

The general block diagram of the fiber-optic sensor is shown above. The block diagram consists of optical sources (light emitting diodes, lasers, and laser diodes), optical fibers, sensing elements, optical detectors, and end-processing devices (optical-spectrum analyzers, oscilloscopes). These sensors are classified into three categories based on operating principles, sensor location and application.

1.2 Types of Fiber-Optic Sensor Systems

These sensors can be classified and explained as follows:

1. Based on sensor location, fiber optic sensors are classified into two types:

Internal fiber optic sensor

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Extrinsic fiber-optic sensor

Internal Type Fiber Optic Sensor

This kind of sensor comprises of detecting inside the actual fiber. Sensors rely upon the properties of optical filaments to change over an ecological activity into a regulation of the light pillar. Here, one of the actual properties of the light sign can be as recurrence, stage, polarization; Intensity. The most valuable element of an inner fiber optic sensor is that it gives dispersed detecting over significant distances. The fundamental idea of inside fiber optic sensor is displayed in the accompanying figure.

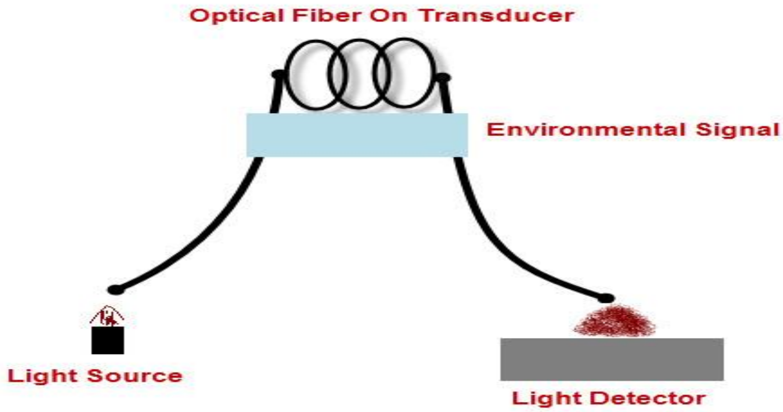

Figure 1.3: Intrinsic Type Fiber Optic Sensors[1]

Extrinsic Type Fiber Optic Sensor

In outside kinds of fiber optic sensors, strands can be utilized as data transporters that guide a black box. It creates a light sign dependent on the data coming in the black box. The black box might be made out of mirrors, gas, or whatever other instrument that delivers an optical sign. These sensors are utilized to quantify

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revolution, vibration speed, removal, winding, force, and speed increase. The significant benefit of these sensors is their capacity to arrive at areas that are generally distant.

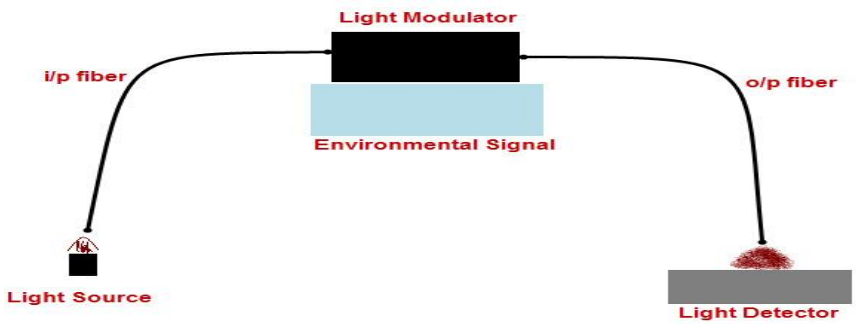

Figure 1.4: Extrinsic Type Fiber optic Sensors[1]

The best illustration of this sensor is the temperature estimation inside an airplane fly motor that utilizes fiber to communicate radiation to a pyrometer, which is situated external the motor. Similarly, these sensors can likewise be utilized to quantify the inward temperature of a transformer. These sensors give great insurance of estimation signals against clamor debasement. The accompanying figure represents the fundamental idea of outward fiber optic sensor.

2. Based on operating principles, fiber optic sensors are classified into three types:

• intensity based

• phase based

• polarization based

Intensity based fiber optic sensor

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Intensity based fiber optic sensors require more light and these sensors use a multi-mode-large core fiber. The figure shown gives an idea of how the intensity of light works simultaneously with a sensing parameter and how this arrangement works as a fiber to a vibration vibration sensor. When a vibration occurs, there will be a change in the light exerted from one end to the other and this will give intelligence to measure the vibration amplitude.

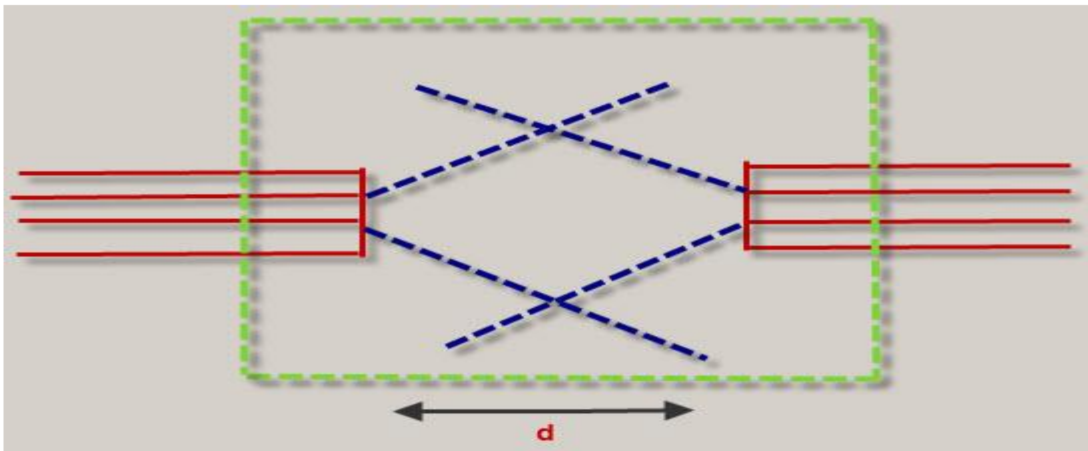

Figure 1.5: Intensity based Fiber Optic Sensor[1]

In the figure, close fiber optic and vibration sensors rely upon the force of light in the last mentioned. These sensors have a few impediments because of variable misfortunes in the framework that don't happen in the climate. These variable misfortunes incorporate misfortune because of flavor, loss of unobtrusive and gross twisting, misfortune because of associations in joints, and so on Models incorporate power based sensors or microbend sensors and transitory wave sensors.

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The upsides of these fiber optic sensors incorporate minimal expense, capacity to proceed as a truly disseminated sensor, extremely easy to carry out, the chance of being disambiguation, etc. Hindrances remember varieties for light power and relative estimations, and so on

Polarization based fiber optic sensor

Polarization-based optical filaments are significant for a specific class of sensors. This property can essentially be altered by different outside factors and accordingly, these sorts of sensors can be utilized for estimation of numerous boundaries. Uncommon filaments and different parts have been created with exact polarization highlights. By and large, they are utilized in different estimation, correspondence and sign handling applications.

The optical arrangement for polarization-based fiber-optic sensors is displayed previously. It is molded by polarizing light through polarization from the light source. Captivated light is started at 45o in chose tomahawks of bifurcated polarization length securing the fiber. This piece of the fiber is filled in as detecting fiber. Then, at that point, the stage contrast between the two polarization states is changed under any outer aggravations like pressure or strain. Then, at that point, as per the outside aggravations, the yield polarization changes. Consequently, by considering the yield polarization state at the front finish of the fiber, outside aggravations can be identified.

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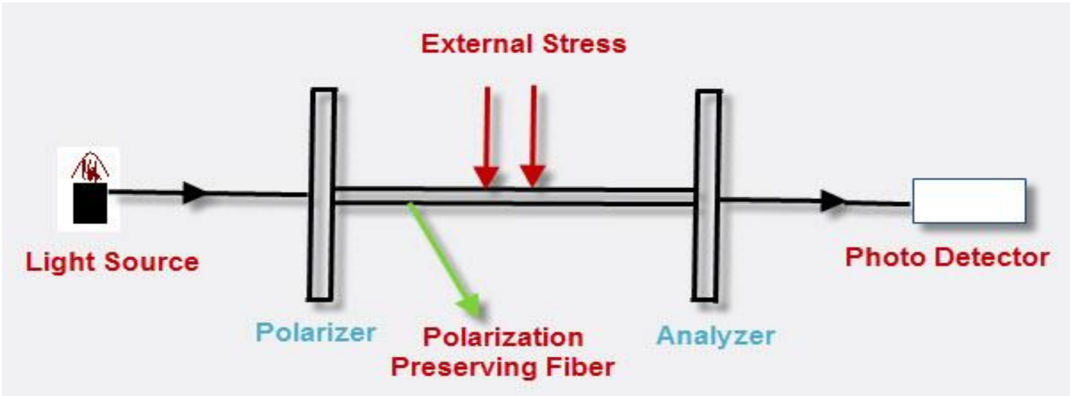

Figure 1.6: Polarization based Fiber Optic Sensor[1]

Phase based fiber optic sensor

This sort of sensor is utilized to supplant the transmitting light on the data signal, in which the sign is seen by a stage based fiber optic sensor. At the point when a light bar is gone through an interferometer, the light is isolated into two beams. One shaft is presented to the detecting climate and the other bar is isolated from the detecting climate, which is utilized as a kind of perspective. When the two separate bars are reconnected, they converge with one another. The most generally utilized interferometers are Michelson, Mach Xander, Sgnac, Grating, and polymetric interferometers. Here, the Mach Xander and Michelson interferometers are displayed underneath. There are contrasts and likenesses between the two interferometers here. As far as comparability, The Michelson Interferometer is regularly considered as a Mach Zander interferometer. The setup of a Michelson interferometer requires just a single optical fiber coupler. Since light goes through the detecting and reference strands twice, the optical stage shift per unit length of the fiber is multiplied. Consequently, Michelson might acquire better affectability. One more clear benefit of Michelson is that the sensor can be grilled with just a

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single fiber between the source and the source locator module. Notwithstanding, a decent quality reflection reflect is needed for the Michelson interferometer.

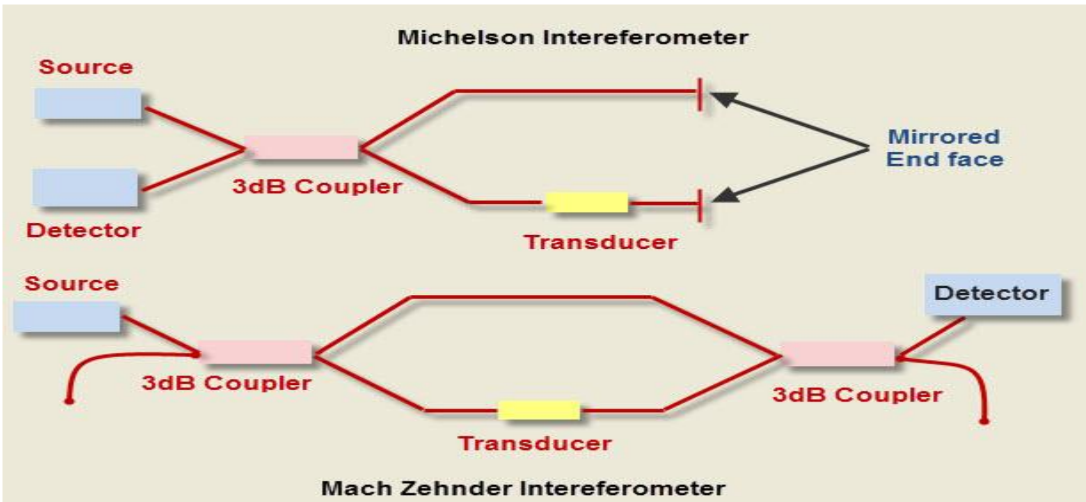

Figure 1.7: Phase based Fiber Optic Sensor[1]

3. Depending on the application, fiber optic sensors are classified into three types such as

- Chemical sensor
- Physical sensor
- Bio medical sensor
- Chemical sensor

A chemical sensor is a device used to convert chemical information into a measurable physical signal that is associated with the concentration of a certain chemical species. Chemical sensors are an important component of an analyzer that may include some devices that perform the following functions: signal processing, sampling, and data processing. An analyst can be an important part of an automated system.

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Figure 1.8: Chemical Sensor[1]

The function of the analyst acts as a monitor according to a sampling scheme as a function of time. These sensors include two functional units: a receptor and a transducer. In the receptor part, chemical information is converted into an energy that can be measured by a transducer. In the transducer part, the chemical information is transformed into an analytical signal and does not show sensitivity.

Physical sensor

A physical sensor is a device that is made according to physical effects and nature. These sensors are used to provide information about a physical property of the system. Such sensors are mostly signed by signers such as photoelectric sensors, piezoelectric sensors, metal resistance strain sensors and semiconductor piezo-resistive sensors.

Bio medical sensor

Biomedical sensor is an electronic device that is used in biomedical fields to transfer various non-electrical quantities to easily detectable electrical quantities. For this reason, these sensors are included in health care analysis. This sensing technology is the key to collecting human disease and physiological information.

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Figure 1.9: Bio Medical Sensor[1]

1.4 Fiber optic sensor applications

Fiber optic sensors are used in a wide variety of applications such as

- Measurement of physical properties such as temperature, displacement, velocity, tension in structures of any size or any shape.
- Monitoring the physical structure of health, in real time.
- Buildings and bridges, tunnels, dams, heritage structures.
- Night vision camera, electronic security system, partial discharge detection and measuring wheel load of vehicles.
- Chemical and Biological Sensing
- Mechanical measurements such as rotation, acceleration, electric and magnetic field measurement, temperature, pressure, linear and angular position, stress, humidity, chemical measurement etc.
- Monitoring physical health of structures in real time.
- Buildings and Bridges: Monitoring of concrete during setting, cracks (length, propagation speed) monitoring, spatial displacement measurement, long term deformation (creep and shrinkage) monitoring etc.

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- Dam: Foundation monitoring, joint expansion monitoring, spatial displacement measurement, leakage monitoring and distributed temperature monitoring.
- Legacy structures: Displacement monitoring, crack opening analysis, seismic damage assessment, restoration monitoring and old-new engagement.
- Tunnels: optical extensometer multiplication, convergence monitoring, prefabricated voltas evaluation, and joint monitoring damage detection.

Thus, the observation of fiber optic sensors and applications is discussed. There are many advantages to using fiber optic sensors for long distance communication including small in size, light in weight, compactness, high sensitivity, wide bandwidth, and more. All these features make the best use of fiber optic as a sensor.

1.5 Optical Fiber Sensor Classification

Optical fiber sensors are classified into three categories [2]: sensing space, operating principle, and applications, as seen in Table 1.1.

Table 1.1: Sensor classification under three categories

Category	Types
Sensing Location	Point Sensors
	Distributed Sensors
	Quasi-distributed Sensors
Operating Principle	Intensity Sensors

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	Phase Sensors
	Frequency Sensors
	Polarization Sensors
Application	Physical Sensors
	Chemical Sensors
	Bio-medical Sensors

Depending on the sensing location, an optical fiber sensor can be classified as external or internal. Internal optical fiber sensors have a sensing area within the fiber and the light never goes out of the fiber. Perturbations act on the fiber and the fibers change some characteristic of the light inside the fiber. In the external sensor, the light has to leave the fiber and reach the outside sensing area, and then return to the fiber. In this case, the fiber serves only as a means of transmitting light to the sensing space.

Depending on the operating principle or modulation and demodulation process, an optical fiber sensor can be classified as an intensity, a phase, a frequency, or a polarization sensor. All these parameters may be subject to change due to external disturbances. Thus, by detecting these parameters and their changes, external disturbances can be realized. Depending on the application, an optical fiber sensor can be classified as follows:

- Physical sensor: used to measure physical proper relationships like temperature, stress etc.

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- Chemical sensors: used for pH measurement, gas analysis, spectroscopic studies etc.
- Bio-medical sensors: used in biomedical applicant ions such as measurement of blood flow, glucose content, etc.

1.6 Result & Discussion

1.1.6 Fiber-optic sensors and the application of PDAM materials to the Enhanced Performance

In the case of fiber optic sensing systems, the response to and response to external conditions and effects is deliberately increased, resulting in more precise changes for precise measurement. Fiber acts as a modulator in fiber sensing systems and also acts as a transducer and provides measurement data for example temperature, stress, strain, rotation, electric and magnetic currents in a corresponding change in optical radiation Converts. Because polarization, frequency, phase and intensity are characteristics of light and any of these parameters can be changed. So the effectiveness of a fiber optic sensor depends on the scale of this change and the user's ability for rapid detection and accurate measurement [1]. Basically the structure of fiber optics is divided into three components such that the core is usually made of glass or plastic, the cladding material that surrounds the core and ultimately the physical damage to the optical fiber [2, 3] To protect from coating or buffer. There are different types of fiber optics sensors for a wide variety of applications. Therefore we can divide these fiber optics sensors into three classes based on the sensing state, the main working process and the application. Depending on the sensing condition, there are two types of fiber optics sensors such as extrinsic fiber optic sensors and internal fiber optic sensors. In the case of

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external fiber optic sensors, the sensing process takes place in the area outside the fiber cable and serves as a medium for back and forth transmission of the fiber cable input optical source (laser, LED, laser diode, etc.) . Position competently and also as necessary. In contrast, the internal fiber changes one or more physical properties (polarization, phase, intensity, frequency) of the fiber of the fiber and consequently the fiber changes the characteristics of the optical source inside the fiber [1, 4, 5, 6].

Fiber optic sensors can be classified based on their different types of applications. Physical FOS is commonly used to measure various types of physical properties such as temperature, stress, etc. Chemical FOS is commonly used to determine chemical properties for pH measurement, gas analysis, spectroscopic studies, etc. While biomedical FOS is commonly used in various types. Medical applications such as blood flow, determining glucose content, etc. are a variety of fiber optic sensors based on the basic working principle of the main fiber optic sensing systems such as intensity, phase, polarization, and frequency. All these parameters can change their values and properties due to different circumstances. Therefore by detecting change, we can actually measure change in circumstances [1, 4]. In general, all types of FOS fall under two groups such as external type or internal type. The sensing state is the most important role when grouping any type of FOS. If the sensing process occurs outside the fiber, it is the external type. On the other hand, if the sensing process occurs inside the fiber, it is the internal type or is also known as "all-fiber". The most important and very influential subclass of all-fiber sensors is interferometric sensors and many powerful and highly capable sensors fall into this category. It is clear that, almost any kind of environmental result can be detected and then converted into an optical signal to be interpreted appropriately

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for appropriate application. In general, each environmental outcome can be determined by different types of fiber optic sensors. Here, the main concern and goal is to select the most suitable fiber optic sensor that can specifically understand and measure the desired environment in the most effective and accurate way.

1.6.2 Recent Developments of FOS Based Applications

Fiber optic sensing technology and applications in various fields have been improving so rapidly in recent years and are continuously making a positive impact in the latest science and technology progress. Some notable results of this technique were identified in areas including high-resolution underwater acoustic sensing, strain monitoring, rotation sensing (gyroscope), chemical / biomedical sensors, pH sensors, optical fiber nanotapper sensors, two-amplitude fiber optic sensors has gone. And long range linear measurement, temperature sensing etc. optical fiber sensors have managed to attract enough attention due to the number of distinct advantages such as light weight, very compact and small design, easy multiplexing and most of all it is unaffected by electro. -Magnetic interference (EMI).

Above all, these sensors do not require an external electrical power source at the exact sensory location and in most cases have the ability to be manufactured at relatively low cost [9, 10]. Suozhu Wu et al. [11], a mode-filtered light fiber optic pH sensor was successfully designed and developed to detect and determine pH levels in an effective way. Cresol red (pH detection level 9.0–13.0) and Bromocresol green (pH detection level 2.0–8.0) were used as pH indicators in this sensing technology system. Although this specifically merged pH sensor is very effective and practically unaffected by most citations but some potential candidates

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were K + and Pb2 +. The Bromocol Green pH indicator caused some trouble regarding these possible interventions [11]. Furthermore the pH sensor, especially the Bromocol Green pH indicator, is highly sensitive at certain cations (K + and Pb2 +). But, it actually covers the range of 2.0–8.0 and 9.0–13.0 and realizes the sample properly and shows no irregularity. The authors also proposed some custom made pH indicators that theoretically perform at a better speed, and show more accurate measurements. Suozhu Wu et al. [12], successfully designed, built and fabricated a chemo-sensor based on mode-filtered light technology (MFLD) to detect the presence of methane (CH4) gas in ambient conditions. In this case, the original sensor is incorporated with a custom-made fiber optic cable, covered in a fused-silica capillary with a thin silicon cladding of cryptophene A. This sensor certainly has some very specific and useful features such as low level detection, lower baseline intensity, very fast and active sensitivity and complete flexibility to select detection points. Upon detection there was almost negligible interference from oxygen, hydrogen, and carbon dioxide, but interferences with dichloromethane and carbon tetrachloride were found during the experiment. All in all, it is a very promising, extremely useful and exhibits tremendous potential in detecting methane gas present in the surroundings. With further research and other cladding being properly integrated by the right host compounds, this specific sensing technology can also be applied to detect the presence of other neutral gases. In this case, the custom-made FOS is specifically equipped as a column in a coated capillary optical fiber (a special type of waveguide) system. Fundamentally, this FOS is capable of detecting and identifying different compounds of a concentration, but it cannot determine their concentration. Furthermore, the opto-fluidic setup cannot withstand high temperatures in this specific experiment, which

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is why it is performed at 29 ^{o}C. In addition, the acceleration of a gas decreases the amplitude of a velocity peak and increases its width. But this thesis also suggests that this situation can be avoided by improving the resolution of optical sensors. A notable advantage of this FOS over a typical gas chromatography detector (GC detector) is that, the time taken to reach a peak of this specific FOS does not depend on the column length. All in all, this sensor has the great ability to quickly feel and see different compounds before leaving the column and can also accurately estimate their retention time. This advantage can therefore be used as a real-time modification of GC parameters, especially in long columns, where analytics have extended retention times. a. Khiyat et al. [16], a special type of fiber optic sensor was designed and developed to understand and determine two types of linear displacement. This sensor can determine the resolution in nanometer scale and the range in millimeter scale. After the sensor theory is tested and applied in a specific direction, then the displacement process for two-dimensions is also explained, used and the resulting measurements are sensed using this FOS and high precision actuators. . There is also a limitation in this FOS measurement technology. In terms of resolution, the best and worst displacement cases are occurring at 27.4 nm and 38.7 nm and for the range it is 8.67 mm and 13.03 mm, accordingly. The main advantage of this high-resolution FOS is the ability to realize long-range linear displacement in an aircraft. By using this specific method, there are some useful benefits such as better range of resolution (27.4nm) and higher speed, respectively. In addition, the longest measurements were reached using the second method (13.03 mm). However, it was narrower than the size of the silicone grating (14 mm x 14 mm).

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1.6.3 Application of PDMS Material in FOS Technology for Enhanced Performance

Polydimethylsiloxane (PDMS) is a very interesting and exceptional type of silicone elastomer or silicone rubber that has very useful properties as a base material for various sensory applications. It has a unique capability of cross-linking without any kind of difficulty, making it one of the primary options for many micro and nano-cast applications as a base material or coating material. Furthermore, PDMS materials have excellent dielectric properties and do not fluctuate much with variation in temperature. Table 4.2 shows the detailed changes in properties according to temperature changes [35].

Table 1.2: Dielectric Properties

Property	**Temperature**		
	35°C(87°F)	**100°C(215°F)**	**200°C(395°F)**
Dielectric Constant	2.9	2.6	2.4
Loss Factor	1.3E-05	1.3E-05	1.6E-05
Specific Resistance (Ohm-cm)	4.E+17	6.E+16	1.E+16
Dielectric Strength	125	110	100

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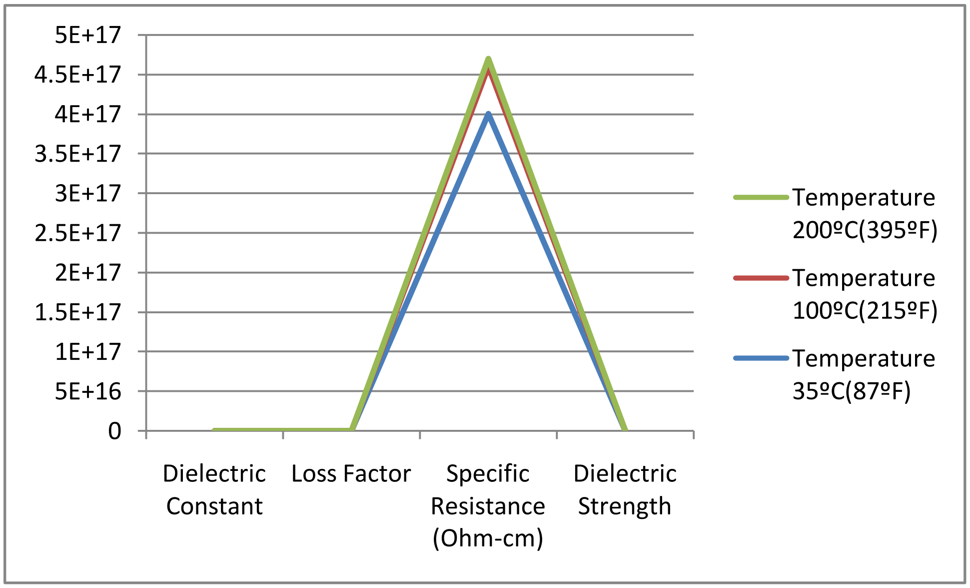

It is clearly indicated in Table 1.2 that the dielectric constant, loss factor, specific resistance, and dielectric strength of the PDMS material do not change so much as the temperature changes. The basic performance properties of PDMS materials are listed in Table 1.3 [35].

Table 1.3: Performance Properties

Characteristics	Value / Appearance
Color	Water White
Chemical Stability	High
Electrical Conductivity	Nil (Insulating)
Surface Tension	$\leq$ 31 dynes/cm
Refractive Index	~1.5
Water Solubility	Essentially nil
Viscosity Range	0.71 to 30,000,000 cs

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Growth in Micro-Organisms	~Nil

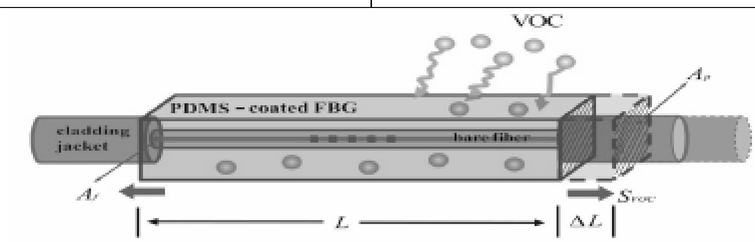

Figure 1.10: PDMS-coated FBG sensor.

Currently PDMS materials become one of the primary options due to their unique and useful features such as flexibility, elasticity, transparency, biocompatibility and easy manufacturing process. Unique properties of PDMS materials such as very high flexibility and elasticity are able to provide great distortion in creating a variety of functional structures for different purposes. In contrast, PDMS materials also have some limitations. Due to its unique porous structure, PDMS has high permeability. Therefore it requires particularly high sealing in the case of some devices such that it would be very difficult to maintain the pneumatic pressure in an instrument [36, 48]. In the case of fiber optic sensing technology, PDMS can be used as a coating material to enhance sensing and measurement performance [37–43]. By applying the FBG sensor, environmental disturbances on the FBG sensor, such as stress, temperature, and pressure, can be directly calculated by monitoring the degree of Bragg wavelength shift induced by the amount of FBG twist. However, for chemical sensitization purpose, ordinary FBGs are not fully suitable for practical applications because optical fibers do not respond to chemical solutions. Furthermore, conventional FBGs are not intrinsically sensitive to a surrounding medium refractive index (SRI) variation because the optical field is well bonded within a fiber core and a light coupling with SRI is sampled by a thick

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casing layer. goes. So to overcome these problems, long-term fiber grating (LPFG) is commonly used for chemical sensing applications, where light coupling exists between the core and the cladding mode, an optical interaction is associated with Which combines cladding and an external medium [34] 42–47]. Figure 4.10 represents the basic installation and working process of PDMS material in FOS-based FBG sensors.

This proposed method has already shown remarkable positive output in sensing different chemical approaches. From Fig. 1.11 we can effectively detect various volatile organic compounds by observing different transmission spectra [47]. This specific PDMS coated FBG sensor can carefully detect the type and concentration of VOC by closely observing the Bragg wavelength shift.

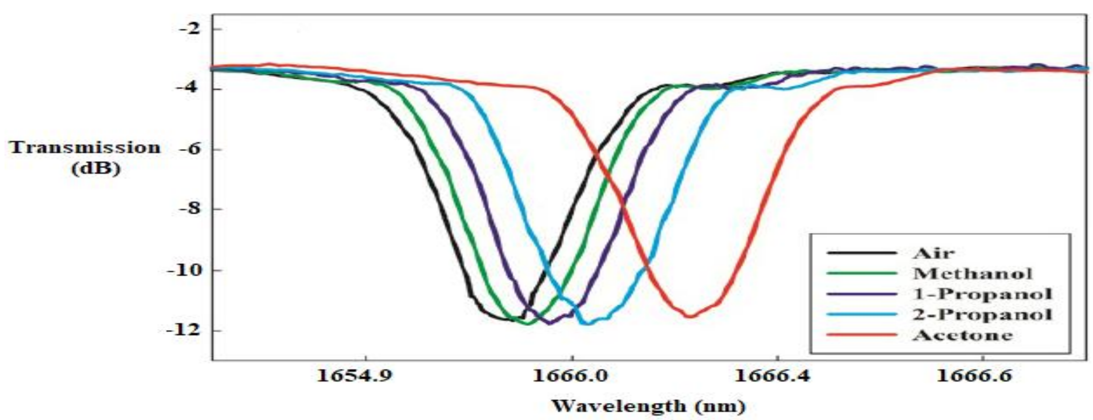

Figure 1.11: Different Optical Fiber Sensors technique and performance of transmission spectrums

Conclusion

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The Various types of Optical Fiber Sensors technique and their Applications Performance and detailed classification is discussed in this chapter. In recent years, various types of sensing techniques and methods are also being reviewed and discussed in this chapter. It turns out that all these FOSs have some kind of insufficiency due to some limitations. They have a specific threshold for realizing specific parameters and in some cases are being incapable of judging rationality and change. But these problems can be overcome with the help of extensive modern research, improvement and use of appropriate modern components. The overall sensing performance and accuracy can be significantly improved by applying PDMS materials as coating materials for fiber optic sensors. Further appropriate studies and research can improve the overall compatibility between PDMS and fiber optic sensors and will result in better performance and durability.

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